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# Analysis of building drainage and sewer system performance utilizing a tipping tank with water conserving measures

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## Abstract

Efficiently optimised water conservation is an essential tool in achieving sustainable buildings. When designing a building drainage network for servicing a development, recognition must be given to the water throughflow. Reductions to the quantities of the throughflow must be fully understood and should be incorporated into the final design so as to maximise the network's efficiency. The amount of water consumed by occupants is currently increasing. The exploration of water-conserving methods within domestic and commercial buildings continues to grow with the aim of achieving maximum efficiency of the water systems. This paper aims to illustrate that the addition of a tipping tank to a drainage system along with reductions in flush capacities, lowflow showers and behavioural changes of occupants are only a few of many techniques to have been trialled yielding positive results in terms of overall water usage reduction. A major issue associated with the reduction in capacity of any water appliance directly affects the system's ability to perform successfully i.e. remove solids. This paper shows that the reduction of water from a system alone may be counterproductive. Reduced flows may result in an increase in the amounts of operations for the water appliances per unit of drainline carry. The use of a tipping tank, despite the relatively large amount of water required to operate it, can potentially contribute to decreasing water consumption and save more water than it consumes.

## Keywords

Water conservation, computer modelling, water supply drainage, water efficiency.

# 1 Introduction

## 1.1 Improvements to fitting's water conservation

Since the emphasis of water conservation has been placed on fittings, a number of guidance documents and environmental rating incentives have been developed by the UK. The most predominant of which are BREEAM (created by Building Research Establishment in 1990), the Water Efficient Product Labelling Scheme, the Water Technology List and the Enhanced Capital Allowance Scheme (all endorsed by DEFRA). The Water Technology List was published in 2003 and provides extensive information on almost all W.C.'s in use in the Scotland. As a result of these developments, the maximum flush capacity for a Scotland W.C. is now between 2.9-6 litres and a high percentage contain dual-flush options. Overall in the UK From 1st January 2001 the 1999 Water Regulations (Department of the Environment, Food and Rural Affairs, 1999) specify a maximum flush of 6 litres. Homes with W.Cs installed pre-1999 will have significantly larger cisterns with flush volumes of up to 13 litres.

## 1.2 Out-of-date building standards still effecting water systems

Before suggestions to improve the water distribution system through improvement in fitting performance can be made, it is important to analyse the entire system to ensure that the proposed changes would actually make a beneficial and meaningful difference. Currently, the internal DWV system of a domestic building is comprised of a series of pipes all with a diameter of 100mm or less, but the main soil pipe has a diameter of 100mm. The reason for this diameter is that the connection flange on a toilet is 3 inches (approximately 75mm) and the connecting pipe cannot be smaller than the flange diameter. In the UK, this is not a regulatory requirement but it is the norm.
The size of the pipe, not the fitting, then dictates the system's performance and so sufficient consideration should be afforded to the pipe's diameter too. Thus water conservation addressed through reduced W.C. flush volumes, reduced white goods water consumption or a move to reduced flow showers and user sensing urinal flushing, must be accompanied by an assessment of drain sizing that will yield comparable performance at the reduced flows likely to be encountered in the future since it is the performance of the whole DWV system that matters.

## 1.3 Economic rationale for water conservation

Alongside the obvious fact that less water used equates to less water needing to be supplied, there are many other economic benefits that complement the environmental benefits associated with creating water conservative drainage systems. The economic rationale for water conservation is one that has failed to resonate with end users due to the fact that a reduction in usage does not directly translate into monetary reward. If a sustainable plan for water conservation is in place, the water industry will have the opportunity to accurately gauge usage over a sustained period and project the benefits.
Similarly, reductions in water use imply further economies as the existing drainage infrastructure could handle increased occupancy following change of use—a possibility in redeveloped 'brown' site building programmes. It may be argued that the advantages of water conservation will be offset or wholly negated if the outcome for the consumer, either in the domestic or commercial sense, is a rise in maintenance charges brought about by inefficient drain cleansing due to reduce through-flows.

As the predominant percentage of the drainage flow, from a single appliance category, within the building envelope will emanate from W.C. discharge it follows that the interaction between W.C. operation and the drainage network performance should form the basis for drain sizing design criteria.

## 2 Intermittent discharge devices

One practical method, which has been suggested as an additional tool to reduce water usage in systems is the implementation of an intermittent discharge device or tipping tank. Previous research, exploring tipping tank utilisation in sewer networks, aimed to reduce sewer maintenance costs and intended to offer a technical alternative that could contribute to the extension of sewage services.

The placement of sewer networks in areas without significant gradient has continued to be problematic. To fabricate a slope sufficient enough to assure the self-cleansing of sewage collector pipes results in increasing depths of excavation and pipe laying, which leads to appreciable increases in construction costs.

The application of flush devices also has great importance in areas where water conservation is in practice. Such programs often focus on the reduction of the amount of discharge volume in domestic appliances. This leads to a focus on W.C.'s as they are responsible for most of each house's water consumption.

In the hope of finding a solution which did not compromise on performance but successfully reduced the water consumption of a system, Brunel University developed a tipping tank to explore flushing alternatives. The main objective of the research was to create a tipping tank that could operate at the head of sewer collectors, whilst receiving all of the domestic waste water. This would then, in turn, allow the reduced discharge volumes of appliances (Swaffield, J.A. 1991).

In Scandinavia, syphon tanks continued to be developed (i.e. by SoVent) and used due to the introduction of the 3 litre discharge capacity W.C. The focus of this Swedish syphon tank was to serve isolated or grouped dwellings by being supplied by waste water. Constructed of plastic and with a volume of approximately 20 litres, the implementation of these devices has been successful in Sweden.

## 3 Testing the tipping tank

A prototype of a modern commercial tipping tank with a volume comparable to contemporary W.C.'s was obtained for testing and the tank's discharge profile was established.

Drain loading calculations have evolved slightly from the original work (Hunter, R. B. 1940) on the fixture unit/discharge unit design method. Values for each W.C. types needed to be assigned and a test to determine the discharge profile for each needed to be developed. Particular focus also needed to be given to the W.C.'s duration and peak flow.

Numerous methods have been utilised, falling into two main categories, namely a mass versus time record and a volume discharge versus time record.

An earlier researcher (Pink, B.J. 1973) presented a form of the mass versus time record that illustrates the fundamental problem with this mode of measurement may be a necessity to "take out" the momentum of the discharge flow. This inevitably damps the peak flows recorded.

Uujamhan (1981) utilized the volume versus time methodology, however due to the

formation of “waves” on the surface of the collection tank, “noise” was introduced into the readings.
Heriot-Watt University developed a method of calculating the discharge profiles of appliances prior to the turn of the century. Figure 1 illustrates where the volume versus time graph is obtained through a system of depth measurement at a range of locations corresponding the principal nodes and antinodes of the first three degrees of freedom over the surface of the collection tank. A pressure transducer records the average air pressure in vertical tubes distributed across the surface of the tank caused by changes in the rate of water surface height. There are 12 vertical tubes connected to 12 monitoring points and Figure 1 illustrates a comparison of the results obtained by each. The problems associated with the previous test methods are removed using this technique and the output has very good sensitivity and immunity from noise, permitting the detection, for example of the difference between a 6 litre clean flush of a W.C. and the same W.C. with 6 sheets of toilet paper included. This allows progress in improving models of drain loading and W.C. fluid contamination removal (Swaffield, J.A. 1993).
The results of the laboratory test procedure are illustrated in Figure 2. The graph demonstrates the discharge profile of the tipping tank which is then input into DRAINET for the simulations.
With the discharge profile calculated, the specialist drainage simulation software, DRAINET, could be updated.

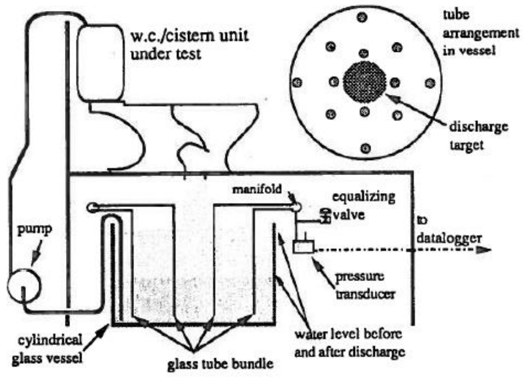


**Figure 1 Schematic diagram of the device used to measure the flush characteristics of the tipping tank. It averages the air pressure increase in 12 glass tubes submerged in a tank of known dimensions (Swaffield, J. A. 1993)**

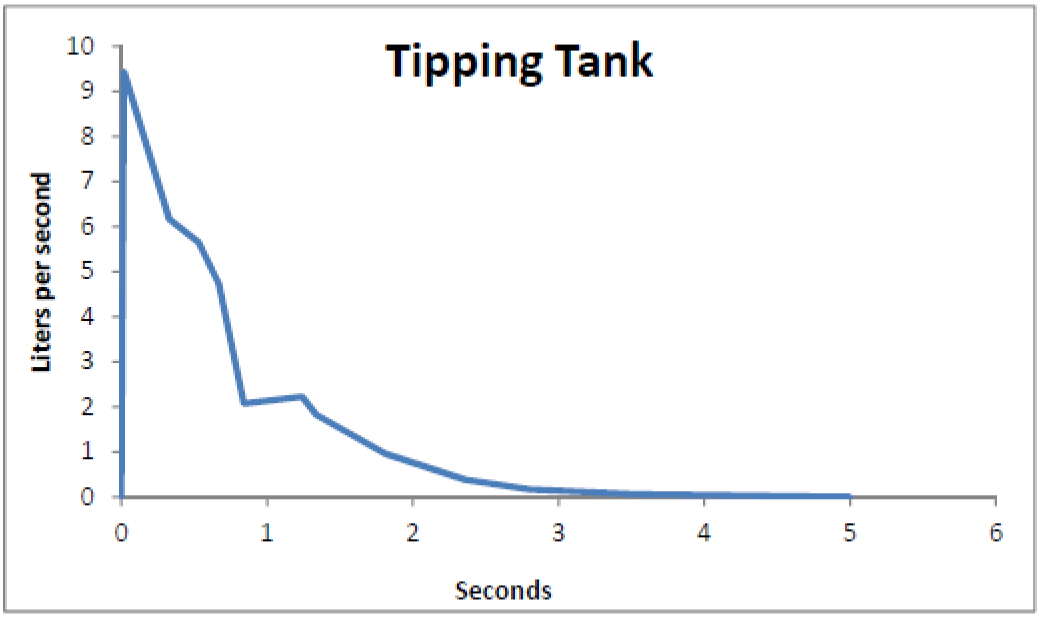


**Figure 2 Discharge profile of tipping tank tested in the laboratory**

### 3.1 Computer simulation software – DRAINET

A key tool in the study is a computer simulation package known as DRAINET which can simulate scenarios concerning drainage systems in general in order to determine the performance without having to construct the system or a physical model. When a simulation is run the program provides accurate predictions of flow depth, flow velocity, solid velocity and solid position represented clearly in graphical form.

Using DRAINET, it is possible to simulate drainage system configurations and then to conduct sensitivity analyses which can then be used to influence design procedures. The aim of this approach is to minimize potential maintenance problems while, at the same time, encourage water conservation. DRAINET is based on a finite difference scheme and utilizes the method of characteristics as a solution technique to simulate drainage system operation. This is done via the equations that define unsteady, partially filled pipe flows and the boundary conditions represented by pipes, junctions and other common system components.

A system, hypothetical or representing a real-life system, can be built up through the simple graphical user interface representing pipes, junctions and sanitary appliances etc., assembled schematically to represent the system.

### 3.2 Layout for drainage simulation runs

A regional water authority (Scottish Water) provided information related to a housing development in west central Scotland (Paisley). The development, Waulkmill Avenue, consisted of a number of houses with a known occupancy value for each. This, coupled with information on the layout of water appliances within the house, was then used to create a model within DRAINET.

The flow profiles for the shower, sink and W.C. were modelled in the Heriot-Watt University services laboratory and their capacities and length of time for operation were aligned to industry standards.

With regards to the dishwasher, washing machine and sink's flow rates and capacities, the

UK averages were found from research and these were incorporated into the simulation. One of the most important aspects of this research was the length of time at which it took the appliances to operate. On average, a dishwasher would take two hours to complete a wash cycle, this was the greatest length of time of any of the appliances. As a result, the entire simulation could not be run for any less than 7200 seconds with the diversity factor chosen. It was decided that it would run for 7300 seconds to ensure all appliances' discharge were accounted for.

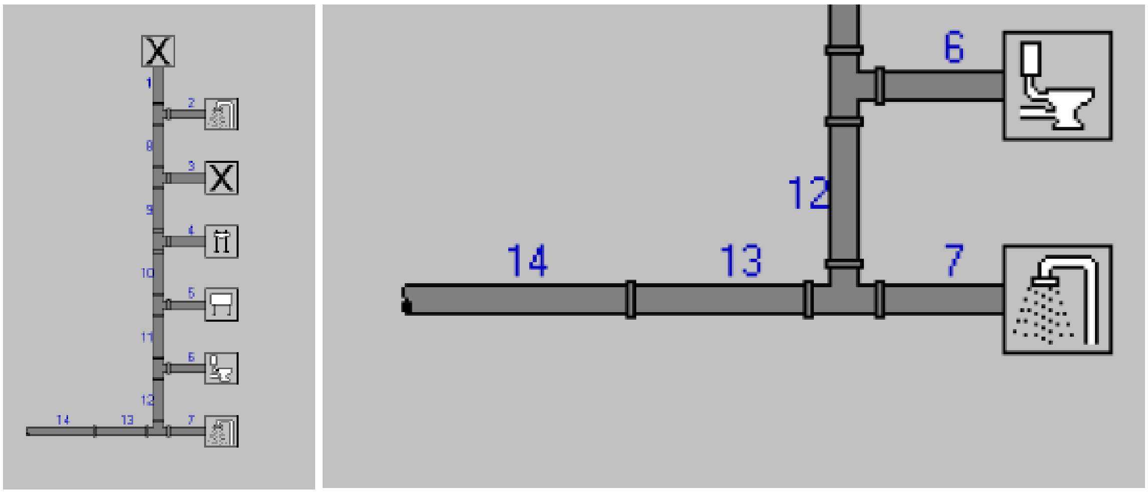


**Figure 3 Single house layout with a close up of the solid's route from the W.C. to the outlet pipe and exit. Image is not to scale**

Figure 3 depicts the layout of one house used in the simulations. The appliances were all assigned operation times to prevent a mass surge of water being input into the system. During the running of the simulation, only 3 types of appliances would experience a reduction in capacity/water conservation methods: W.C., showers and basin. The reason for selecting these appliances was based on them being the largest, in terms of capacity, within the dwelling with the exception of the basin, which was chosen because of the frequency at which it is used. A reduction in the operating capacity of the basin alongside no reduction in the W.C. does not render any change to the travel distance of the solid. The amount of water discharged by the basin is, therefore, negligible and does not affect the objective of the analysis of these runs. Each of the appliances was then subjected to a reduction in their capacities (80% and 60%) and every possible combination was then simulated.

### 3.3 Terraced housing

The purpose of the tipping tank is to reduce the overall water usage in housing developments whilst maintaining the required standards of drainage system performance. As a result of this, it would not be prudent to install a tipping tank into each individual property but to strategically place it so that it can benefit numerous properties.

With regards to the site at Waulkmill Avenue, there are terraced houses with 4 adjoining properties sporadically placed around the development. Therefore, the DRAINET model has been modified to include 4 identical, adjoined properties to the example used previously in this section (Figure 3). The exact same water conservation simulations were then performed.

*3.3.1 Terraced housing: solid travel distances*

The results, in terms of solid travel distance, are as shown in Figure 4.

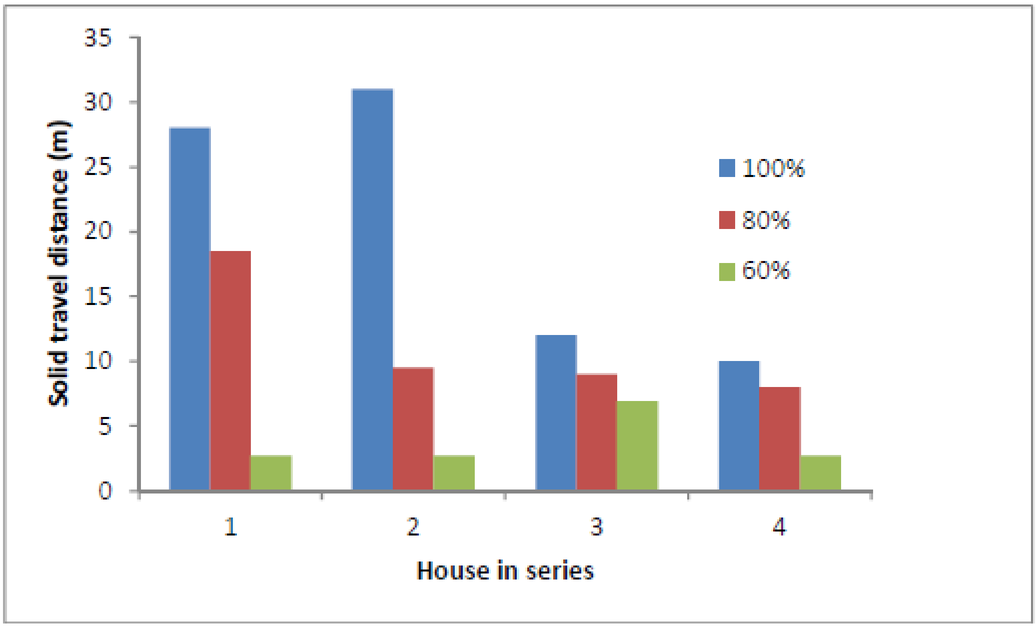


**Figure 4 Graph of solid travel distance each house in series**

It can be seen in Figure 4 that there was a reduction in the overall travel distance by the solid as the W.C. operating capacity dropped from 100% to 80% and 60%. The change in distance, however, is not linear with a large change observed between houses' 1 and 2 transport distance and with much smaller effect being observed in houses 3 and 4.

A reduction in the operating capacity of the showers alongside the W.C. culminates in a loss of travel distance for the solid. As predicted, the solid travels the least distance when the W.C. and showers are all operating at the minimum capacity, 60%.

It can be seen that the travel distance is only affected by the reduction in operating capacity of the shower alongside the W.C. The basin does not have any bearing on the results.

*3.3.2 Terraced housing: solid behaviour*

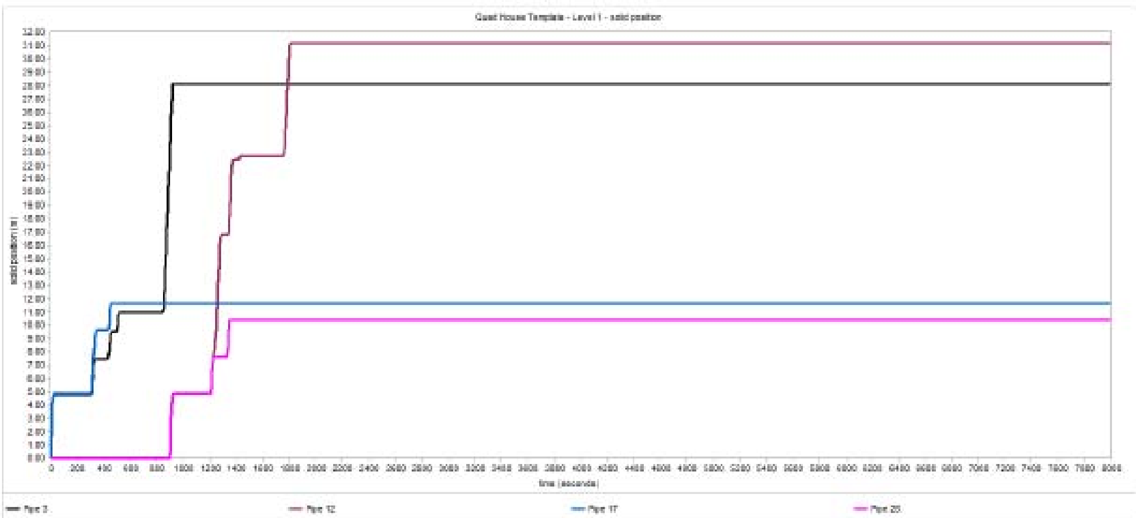

**Figure 4 Solid position when appliance operation at 100%**

The graph in Figure 5 depicts the movement of the solids that enter the W.C. during the simulation. It can be seen that the solids from house 1 (pipe 3) and house 2 (pipe 12) have a significantly greater carry distance than house 3 (pipe 17) and house 4 (pipe 26). This is the repercussions of the water output of houses farthest from the combined sewer pipe helping to move the solids entering further downstream towards the communal sewer pipe. The surge of movement from the solids from houses 1 and 2 can be attributed to the usage of an appliance (W.C. or Shower) from a house downstream of the pipe system. The graph in figure 5 also gives an insight into the behavior of the solid during times of low flow since its deposition will therefore require water flow with a large enough shear force to dislodge it from where it has deposited. This is testament as to why only appliances with a large flow profile (W.C. and shower) were considered for water conservation measures.

The levelling off of the graph line is a result of the solid remaining stationary in the outlet pipe despite their potentially still being water flow within the system. The solid has failed to completely leave the DRAINET system but it travelled a sufficient distance to suggest it made it out of the original house's pipe network (over 8m) and into the communal sewer pipe.

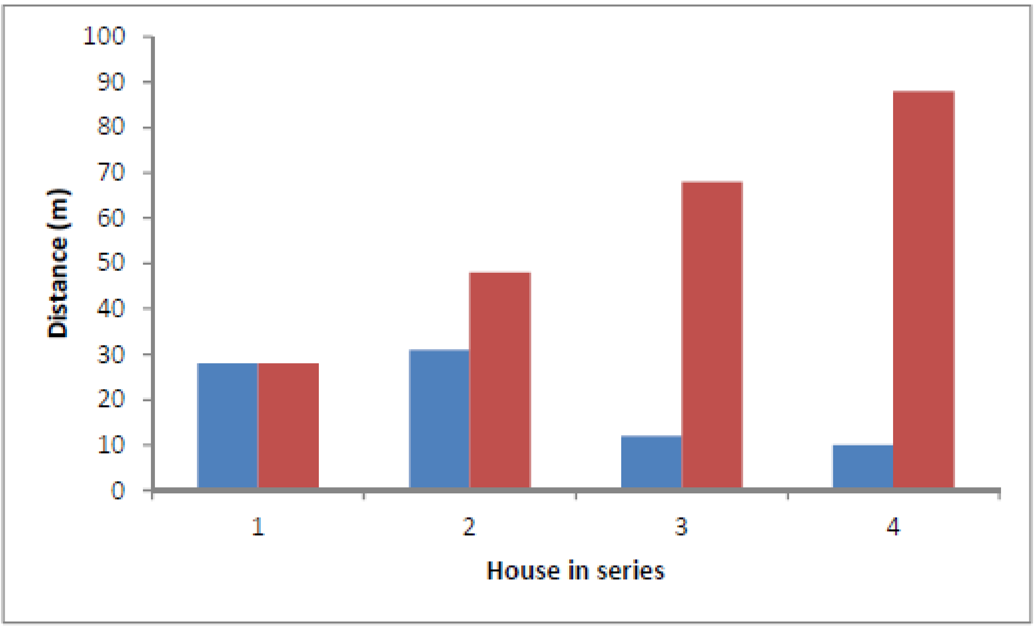


**Figure 6 Solid position vs System end for each solid**

Figure 6 illustrates the travel distance of the solid that enters the W.C. against the total distance the solid has to travel to exit the communal sewer system. The distances each solid must travel to leave the system increase with the addition of each house as they are further from the exit of the communal sewer pipe, therefore expecting all of the solids to leave the system in one operation is unrealistic. With each appliance operating at maximum capacity it can be seen that the solids from houses 3 and 4 travel relatively short distances, 12m and 10m respectively. When the system is reduced to 60% the distances of solid transport from houses 3 and 4 reduces to 6.9m and 2.7m respectively.
From the data provided by DRAINET, the tipping tank in this series of simulations as it was supplied from the manufacturer was a failure due to the solid travel distance being less of that observed in the simulations with the appliances operating at 100% capacity. Due to this lack of solid movement it can be concluded that the use of a small capacity tipping tank does not provide enough force to be maximally effective.
In the series of simulations with the appliances reduced to 80% of the water consumption this has saved approximately 200 litres of water when compared to zero water conservation measures in effect. This impacts the performance of the system. Using this information, a new, hypothetical (but still realistic) flow profile was created for the tipping tank. The aim was to utilise 10% of the water saved accumulatively from the terraced housing, but this time through an 'idealised' tipping tank profile, to demonstrate whether a tipping tank of better design could be beneficial despite the increased water consumption. The tipping tank would then be strategically placed so each of the solids entering the communal sewer pipe are downstream from the tank discharge.

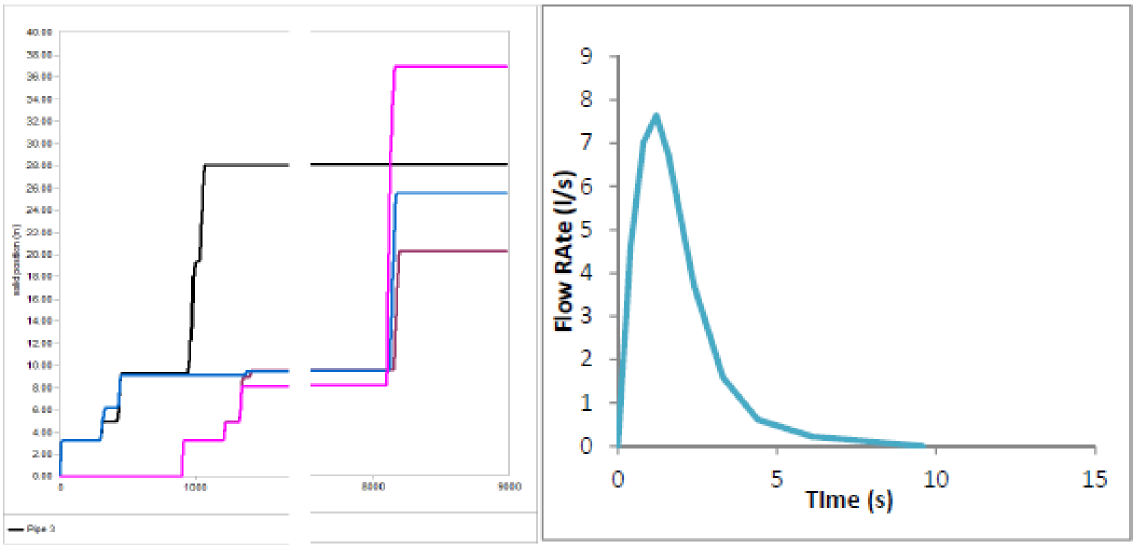


**Figure 7 solid travel distances of the system with the tipping tank and the flow profile of the simulated tipping tank**

*3.3.3 Terraced Housing: Conclusion*

In order to test the theory of using 10% of the conserved water, a new discharge profile was created and adjustments were made to create a more 'ideal' profile. Figure 8 displays the flow profile of the modified, computer-generated tipping tank. DRAINET data shows that with the modified tipping tank, there is a significant increase in solid transport distance from houses 3 and 4. A single discharge at the end of the initial DRAINET simulation showed increases in distance of 108% and 260% of solids 3 and 4 respectively, while maintaining a net water conserved regime.

## 4 Planned research continuation

The goal of the research was to establish whether or not introducing a tipping tank to a series of domestic properties could improve the overall efficiency of the DWV system and DRAINET simulations have shown this to be a potentially viable option.

Based on the results obtained from the DRAINET simulations, it is clear that the tipping tank must have the correct discharge profile in order to be effectively utilised. With the correct discharge profile in place, and with suitable dimensions and capacity, a sensitivity analysis can then be performed to determine the most efficient tipping tank usage scheme. With this information, it would then be possible to determine the most water-efficient combination of appliances within the DWV system without having an adverse effect on its overall performance.

The varying nature of housing developments would have to be considered. Housing positions, distances to communal sewer pipes and occupancy all vary around Scotland and the UK. Therefore, numerous sites must be modelled to deduce whether the placement of a tipping tank at Waulkmill Avenue (upstream from House 4) is the most prudent position for each individual development. Perhaps smaller, more frequently place tipping tanks would prove more successful; this should be tested.

Water appliances continue to evolve with the development of new technology and regulations. As a result, tipping tank design will have to follow suit and reflect the changes occurring within DWV systems.

# 5 Conclusion

DRAINET simulations with a maximally water conserved system indicate that the solid transport distance is less than with a non-water conserved system.
DRAINET simulations with a computer generated tipping tank demonstrate that in areas with water conservation appliances, tipping tanks can increase solid transport in the DWV system and can lead to water consumption reduction despite their additional water consumption.
DRAINET simulations with a computer generated tipping tank results in solids increasing their travel distances. This indicates that the application of a tipping tank has the potential to result in an improvement to drainage systems.

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